IMPROVING SOIL BEHAVIOR PREDICTION FROM FIELD MORPHOLOGY

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INTRODUCTION

We present several approaches to increase the value of morphological observations for soil behavior prediction.

PROPOSALS

1. Three classes of moist. The 8 class set for water state (Soil Survey Div. Staff, 1993) has three subclasses of moist -- very moist, moderately moist, and slightly moist. Very moist is from 1 to 10 kPa; moderately moist is from 10 kPa to the midpoint retention between 10 and 1500 kPa; and slightly moist is from the same midpoint to 1500 kPa. In the 3 class set, moist extends from 1 to 1500 kPa. The range is so large as to have questionable usefulness. General acquaintance with field capacity makes the very moist - moderately moist separation feasible. The moderately moist - slightly moist separation is widely used in irrigation scheduling. The greater utility of the three classes of moist overweighs the greater uncertainty in placement.

2. Apply ashes of hydrogen. The proposal is to moisten 0-50 cm, if needed, to near field capacity, before describing structure and rupture resistance. Insert a ring 30 cm diameter and 15 cm high deep enough that the water does not move laterally rapidly at the ground surface. The volume of water to add is the product of layer thickness and the deficit (θd):

$$\theta_d = \theta_{mv} - \theta_x$$

Where θ_x is the initial field water, and θ_{mv} is the upper boundary of very moist (Soil Survey Div. Staff, 1993; 1 kPa) taken as field capacity (upper boundary of θ_{mm}) plus half the calculated air-filled porosity at field capacity based on the computed total porosity (ρ_t):

$$\theta_{mv} = \frac{\rho_t + \theta_{mm}}{2}$$

The upper class limits of the field water state classes to follow are the reference on which the estimation of θ_x is made. No > 2 mm is assumed and for simplicity the bulk density at field capacity is applied at water contents below field capacity. θ_{15} is used throughout, calculated as follows if not available:

$$\theta_{15} = \frac{\left[\left(Clay \times F\right) + \left(1.7 \times OC\right)\right] \times \rho}{100}$$

θ_{15} - 1500 kPa retention
F - Factor, commonly 0.40
OC - Organic Carbon
ρ - Bulk Density

$$\theta_{mm} = WRD + \theta_{15}$$

Moderately moist. 10 kPa retention. WRD = Water Retention Difference, 10 to 1500 kPa.

$$\theta_{ms} = \theta_{mv} - \frac{\theta_{mm} + \theta_{15}}{2}$$

Slightly moist. Midpoint 10 and 1500 kPa retention.

$$\theta_{ds} = \theta_{mv} - \theta_{15}$$

Slightly dry.

$$\theta_{dm} = \theta_{mv} - \left(0.8 \times \theta_{15}\right)$$

Moderately dry.

$$\theta_{ds} = \theta_{mv} - \left(0.35 \times \theta_{15}\right)$$

Very dry.

In the field the nearest upper limit of a water state class is estimated, which becomes θ_x. The difference from θ_{mv} is the volume fraction deficit (θ_d).

PROPOSALS, cont.

3. Toting tilth. The purpose is to evaluate at about field capacity the morphology 0-30 cm. Separate the zones on class changes in structure and/or rupture resistance. Place each kind of observation in classes 1 to 5. Obtain an index for structure and rupture resistance combined, weighing rupture resistance more for coarse textures. Reduce the indices for crust and increase for surface connected macropores. Obtain a depth-weighted average index for each 10 cm and combine, weighting the uppermost 4, the middle 2, and the bottom 1. The complete system has been submitted for publication by the ISCO Conference.

4. How stuffed is the stuff. The purpose is to present a procedure to estimate bulk density in the field. No organic carbon is assumed for the first step. Up to 35% clay, the estimate is based on family particle size (without >2 mm), grading, and moist rupture resistance (Table 1). For ≥ 35% clay, the criteria are clay percent, ratio 2-0.1 to 2-0.002 mm, and swelling vs. non-swelling clay.

Next an adjustment is made for organic carbon following Adams (1973):

$$\rho_a = \frac{100}{\frac{OMP}{0.22} + \frac{100 - OMP}{\rho_m}} \qquad (1)$$

ρ_a - Bulk density adjusted for organic matter
OMP - Organic matter percent
ρ_m - Bulk density for zero organic matter

A comparison was made between estimated and measured bulk densities for 233 layers drawn from 62 point samples (Soil Survey Staff, 1975). The equation is:

$$Y = 1.01X - 0.02 \qquad (2)$$

Where X is the estimated bulk density and Y the actual. The relationship has an r^2 of 0.63.

As an example, neglecting organic carbon, a fine-loamy, poorly graded, firm layer has a bulk density from Table 1 of 1.60 g cm^{-3}. This is ρ_m in Equation 1. Assuming 2 percent organic carbon, ρ_a in Equation 1 is 1.32 cm^{-3}.

5. How free is the free water? The first step (Table 2) is to use family particle size (without > 2 mm) and bulk density (previous section) to estimate Ksat of the matrix, free of the influence of large continuous vertical voids. Structure, coatings on structural units, and macropores are then used to obtain a fabric Ksat. Table 3 gives the class of increase in Ksat due to coatings and structure. Table 4 gives for each combination of matrix Ksat class and the structure/coating adjustment class from Table 3 the number of classes that Ksat is increased. Macropores are handled in a parallel fashion, starting from the matrix Ksat adjusted for structure and coatings (Table 2). First the class of increase related to abundance and size of continuous macropores is given (analog to Table 3) followed by the Ksat class increase for each combination of Ksat class as adjusted for structure and macropores and class of macropores (analog to Table 4). Finally an adjustment may be made for roots, which is not discussed here.

Eleven comparisons from the literature were made (Coen and Wang, 1989; Bouma and Anderson, 1973; King and Franzmeier, 1981). Three of the estimates were in the same 3 fold class (0.6-2 in hr^{-1}) as the measured; 7 of the estimates were one class above or below the measured; and one estimate was 3 classes below. For the last, the measured value seems unreasonably high.

Table 1. Estimation of bulk density for sandy and loamy soil materials lacking organic carbon.

Moist Rupture Resistance	Bulk Density [1] [2]							
	Sandy		Coarse-loamy		Fine-loamy		Coarse silty	Fine silty
	Well graded	Other	Well graded	Other	Well graded	Other		
	g cm^{-3}							
Very Firm & Stronger	2.00	1.90	1.85	1.75	1.75	1.65	1.60	1.55
Firm	1.85	1.75	1.75	1.70	1.70	1.60	1.50	1.45
Friable, Very Friable	1.65	1.65	1.55	1.55	1.50	1.50	1.30	1.20
Loose	1.60	1.50	1.50	1.40	1.35	1.30	1.10	1.00

1/ <2mm only. Noncarbonate clay on a carbonate-containing basis.

2/ Well graded has ¼ to ¾ of the 2-0.002 mm in the 2-0.25 mm range and less than 2/3 of the 2-0.25 mm is either 2-1 or 0.5-0.25 mm.

Table 2. Estimated matrix Ksat based on family particle size (> 2 mm excluded) and bulk density; applicable to massive, platy, or weak structure.

Sandy		Coarse-loamy Coarse-silty		Fine-loamy Fine-silty		Clayey	
Bulk Density g cm^{-3}	Ksat Class [1]	Bulk Density [4] g cm^{-3}	Ksat Class [1]	Bulk Density [4] g cm^{-3}	Ksat Class [1]	Bulk Density [4] g cm^{-3}	Ksat Class [1]
< 1.50	Very Rapid	< 1.40 < 1.30	Moderately Rapid	< 1.35 < 1.25	Moderate	< 1.15	Moderately Slow
1.50 - 1.75	Rapid [2]	1.40 - 1.70 1.30 - 1.55	Moderate	1.35 - 1.60 1.25 - 1.50	Moderately Slow	1.15 - 1.35	Slow
≥ 1.75	Moderately Rapid [3]	≥ 1.70 ≥ 1.55	Moderately Slow	≥ 1.60 ≥ 1.50	Slow	≥ 1.35	Very Slow

1/ Interpretive Classes
2/ Very rapid if coarse sand
3/ Rapid if coarse sand
4/ Upper for loamy; lower for silty

Table 3. Classes of increase from matrix to fabric Ksat due to structure and coatings. [1]

Coatings	Structure/Coating Adjustment Class [2]					
	Blocky					Granular
	Very Fine	Fine	Medium	Coarse	Very Coarse	
	Moderate Expression					
None, all few and faint common or many	S	S	S	VS	NA	M
Common or many distinct or prominent	M	S	S	S	VS	L
	Strong Expression					
None, all few and faint common or many	M	S	S	S	S	L
Common or many distinct or prominent	L	M	M	M	S	VL

1/ No adjustment for weak structure or platy. Prismatic or columnar structure and stress or pressure surfaces not included.

2/ VS - Very Small, S - Small, M - Moderate, L - Large, VL - Very Large, and NA - Not applicable (excluded by definition).

Table 4. Number of class increases from matrix to fabric Ksat as determined by matrix Ksat class and structure/coating adjustment class.

Matrix Ksat Class	Ksat class increases dependent on the structure/coating adjustment class				
	Very Small	Small	Moderate	Large	Very Large
Very Extremely, Extremely and Very Slow	1	2	3	4	5
Slow	0	1	2	3	4
Moderately Slow	0	0	1	2	3
Moderate	0	0	0	1	2
Moderately Rapid	0	0	0	0	1
Rapid	0	0	0	0	0
Very Rapid	0	0	0	0	0

Figure 1. Singleton Blade (paint scraper) inserted vertically; resistance to rotation measured with a pocket penetrometer.

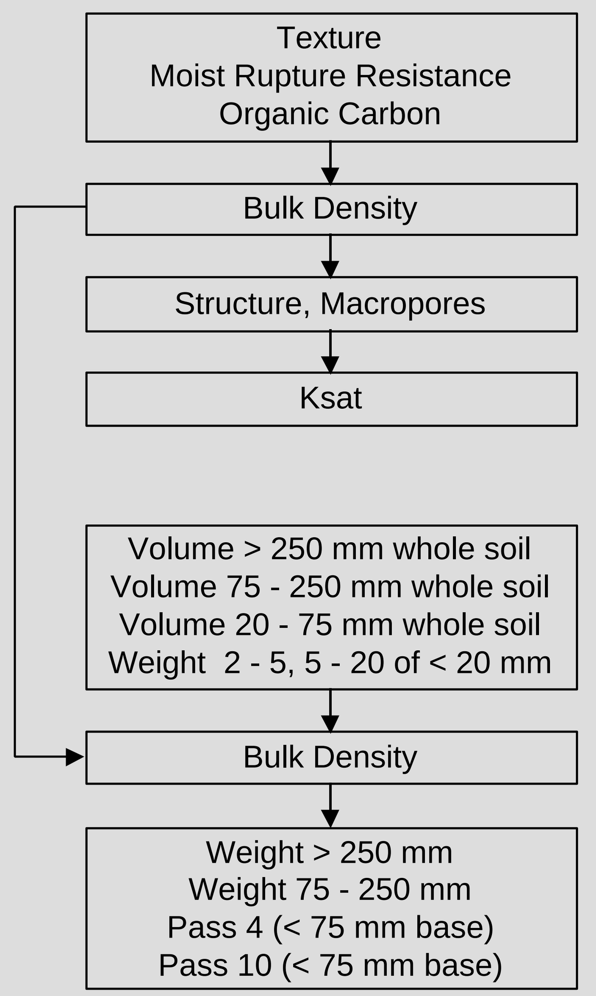

Figure 2. Scheme for deriving several interpretative properties from field observed or estimated quantities.

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PROPOSALS, cont.

6. Extend from the deepest observation. There should be a record for the deepest layer observed -- the change expected below and laterally from that layer. In some instances, it is known that the same formation extends downward many meters. In other instances, it is known that the material is highly variable below the deepest layer. In still other instances, little is known. The same applies laterally. Protocols can be written but first the utility must be recognized. We are not at the stage to consider protocols.

7. Surficial Strength. Figure 1 shows the device which is a kind of Singleton Blade (Griffiths, 1985). The test is performed when the ground surface is wet enough that it glistens but less than the maximum. Insertion is vertical. Measurements are made 0-2 and 4-6 cm. Force to rotate 45° is measured with a pocket penetrometer, usually employing a weaker spring than the standard. Insertion is 2 cm. Insertion area is 4 to 30 cm^2, increasing as strength becomes lower. Force is applied 5 cm from the midplane of the inserted depth. Results are in kg dm^{-2}. The measurement may be predictive of water erosion.

8. Calculous Calculations. Interpretations require on a weight basis >250 and 75-250 mm for the whole soil and Pass 4 (5 mm) and Pass 10 (2 mm) for the < 75 mm. Volume of > 250 and 75-250 mm are commonly obtainable visually; weight measurements require samples that are too large. Visual volume percentages involving 2 and 5 mm limits are not readily made because of the small size. An alternative is to determine the volume percent 20-75 mm for the whole soil and the 2-5 and 5-20 mm on a weight basis for the < 20 mm. (The latter requires only 1 to 2 kg of < 20 mm). Appendix A gives the calculations. The procedure is used by the Federal Soil Survey Laboratory in standard sampling (Soil Survey Laboratory Staff, 1996).

DISCUSSION

We largely describe soils morphologically to identify and classify with less emphasis on behavior prediction. One reason is that behavior prediction has been secondary through the development of soil survey. Another related reason is lack of suitable approaches. We present a near-surface morphology index involving structure, moist rupture resistance, and surface-connected macropores; bulk density estimation from texture, moist rupture resistance, and organic carbon; Ksat prediction from texture, bulk density, structure and coatings, and macropores; surficial strength using a Singleton Blade; and determination of the rock fragment quantities required for interpreations.

Figure 2 shows the inter-relationship of bulk density, structure (coatings) and Ksat, and bulk density and rock fragments. The field observable quantities required are texture, moist rupture resistance, structure and macropores, the volume > 250, 75-250, and 20-75 mm, and the weight percent 2-5 and 5-20 mm for the < 20 mm. Organic carbon would be estimated. A program should be feasible to calculate the interpretive quantities.

Most of the methods pertain to or depend on water state. This applies directly to the morphology index and to surficial strength. It also applies, as shown in Figure 2, through rupture resistance to bulk density and hence Ksat, and to the rock fragment quantities through bulk density.

APPENDIX A

The equations follow to obtain the interpretive rock fragment quantities from the initial observations. These symbols require explanation: W = weight percent; V = volume percent; no prime = whole soil; single prime = ≤ 75 mm; double prime = ≤ 20 mm; ρ = bulk density < 2 mm; $\rho_{\rho 2}$ = particle density > 2 mm.

1. $$\rho_{<20} = \frac{100}{\frac{W''_{2-20}}{\rho_{\rho 2}} + \left(\frac{100 - W''_{2-20}}{\rho}\right)}$$

2. $$V''_{2-20} = W''_{2-20} \times \frac{\rho_{<20}}{\rho_{\rho 2}}$$

3. $$V''_{5-20} = W''_{5-20} \times \frac{\rho_{<20}}{\rho_{\rho 2}}$$

4. $$V'_{20-75} = \frac{V_{20-75}}{1 - \frac{V_{>75}}{100}}$$

5. $$V'_{2-20} = V''_{2-20} \times \left(1 - \frac{V'_{20-75}}{100}\right)$$

6. $$V'_{5-20} = V''_{5-20} \times \left(1 - \frac{V'_{20-75}}{100}\right)$$

7. $$V'_{2-75} = V'_{2-20} + V'_{20-75}$$

8. $$V'_{5-75} = V'_{5-20} + V'_{20-75}$$

9. $$\rho_{<75} = \left(\rho_{\rho 2} \times \frac{V'_{2-75}}{100}\right) + \left[\left(1 - \frac{V'_{2-75}}{100}\right) \times \rho\right]$$

10. $$W'_{2-75} = V'_{2-75} \times \frac{\rho_{\rho 2}}{\rho_{<75}}$$

11. $$W'_{5-75} = V'_{5-75} \times \frac{\rho_{\rho 2}}{\rho_{<75}}$$

12. $$Pass10 = 100 - W'_{2-75}$$

13. $$Pass4 = 100 - W'_{5-75}$$

14. $$V_{2-75} = V'_{2-75}\left(1 - \frac{V_{>75}}{100}\right)$$

15. $$V_{>2} = V_{>250} + V_{75-250} + V_{2-75}$$

16. $$\rho_{>2} = \left(\frac{V_{>2}}{100} \times \rho_{\rho 2}\right) + \left[\left(100 - \frac{V_{>2}}{100}\right) \times \rho\right]$$

17. $$W_{>250} = V_{>250} \times \frac{\rho_{\rho 2}}{\rho_{>2}}$$

18. $$W_{75-250} = V_{75-250} \times \frac{\rho_{\rho 2}}{\rho_{>2}}$$